Globalization and Health

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China's position and competitiveness in the global antibiotic value chain: implications for global health

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Abstract

Background Antibiotics are a key commodity for global health, and inadequate access is a major contributor to global mortality. COVID-19 has refocused attention on global pharmaceutical value chains and the need for sustainable and secure production and supply of key products, including antibiotics. Production of antibiotics and their active pharmaceutical ingredients is capital- and technology-intensive, however, and value chains are dominated by a limited number of countries. China is known to be one of the largest producers, but its position in global value chains has not previously been analyzed. This is important for discussions about equitable and resilient global supplies, including through global instruments such as the pandemic treaty.

Methods This study utilizes data from the International Trade Center database to analyze global and Chinese export trade patterns in the antibiotic industry from 2002 to 2021, along with trends in comparative advantage. The antibiotic trade data included in this study covers different antibiotic products, including some tuberculosis drugs, while other types of antimicrobial drugs (such as antivirals, antiparasitics) are excluded.

Results The export share of antibiotic ingredients from China increased from 9.0% in 2002 to 44.5% in 2021. China is the largest exporter of antibiotic ingredients (with a strong comparative advantage). Additionally, the export share of antibiotic medicines increased from 0.5% in 2002 to 6.5% in 2021, making it the 7th largest exporter of antibiotic medicines (though with a comparative disadvantage). The proportion of antibiotic medicines in China's exports is gradually increasing, though the country's antibiotic industry is expected to remain in the upstream-to-midstream segments of the global supply chain in the short term. China's export market for antibiotic medicines is fragmented, focusing on developing countries, though European (17.9% in 2021) and North American markets (13.1% in 2021) are increasing in importance. China's weight in global antibiotic exports, particularly of antibiotic ingredients, creates dependencies for countries reliant on China, and for Chinese companies reliant on certain overseas markets.

Conclusions China is central to global antibiotic manufacturing. Policies promoting the reshaping of global supply chains and reshoring of critical medicines will likely create challenges for Chinese exporters, though are unlikely to alter the global supply structure in the short term. This has implications for Chinese policymakers, including strengthening innovation, quality, international competitiveness, and diversifying markets. Equally, China's huge manufacturing capability, cost advantages, and rapid scientific and technological progress, make the country an inevitable and important part of future arrangements to ensure equitable global antibiotic access. As the Chinese

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government considers its global health policy in the post-COVID-19 era, antibiotics may provide an area where China can play a distinctive role.

Keywords Antibiotics, Access, Global value chains, China, Antibiotic global trade

Background

Antibiotics are a group ofmedicines that are key to the functioning of effective health systems, and an essential commodity for global health. Lack of access to antibiotics is estimated to cause more deaths globally than antimicrobial resistance (AMR) [1], primarily in low- and middle-income countries (LMICs) [2]. While the reasons for limited access to antibiotics are complex [2–4], reliable supplies are an important element and there is a recognised need for global coordination to ensure this [4].

The COVID-19 pandemic has refocused attention on the importance of complex global value chains in the supply of pharmaceuticals, and the need for sustainable and secure production and supply of key products [5, 6]. The majority of antibiotic medicine supply comes from a small number of countries, including Italy, India, Canada and German [7]. This reflects the fact that antibiotic medicines are a capital - and technology - intensive subsector within biopharmaceuticals. In the antibiotic supply chain, the upstream segment primarily involves raw material production, while the downstream segment is focused on antibiotic formulations. Better understanding global patterns of production and distribution of antibiotics is necessary for ensuring sustainable and secure supply and improving access, especially in LMICs. To date, there have been only a limited number of studies of this [8, 9]. We believe this study to be the first to focus on China, one of the most important suppliers of antibiotics and precursors globally.

As the only country to cover all industrial categories in the WHO Industrial Classification, China has become an important link in global supply chains [10], particularly in industries like pharmaceutical manufacturing, automobiles, and electronics [11, 12]. Since joining the WTO, China's pharmaceutical sector has seen rapid growth, with a significant increase in its participation in international division of labor [13]. In the antibiotic sub-sector, data from the International Trade Centre (ITC) indicate that China's production and export volume of antibiotics was ranked number one globally in 2009 [11], while around 45% of the active pharmaceutical ingredients (APIs) needed for global antibiotics are sourced from China, as shown later in the paper [14]. Moreover, the significant increase in pharmaceutical exports from China to India and the US [9, 15]. Reports from 2020 indicate that India imports nearly 70% of its APIs from China [16]. In 2020-21, China (22%) became the third-largest supplier of APIs to the United States, following India and Italy [17], suggesting an increasing global direct or indirect dependence on supplies from China [18]. Examples of this dependency include a case in 2017 when the shutdown of a single factory in China led to a global shortage of the crucial antibiotic piperacillin-tazobactam, and benzathine penicillin, for which only three API manufacturers remain, all of which are in China [19, 20].

China's antibiotic industry has a long history, though one which sits out the mainstream of antibiotic production and research in developing countries. China's research into and production of antibiotics (initially mainly penicillin, then streptomycin) started in the late 1940s, with development of an antibiotics industry in the 1950s, with backing for research centres and state-owned facilities from the central government and support from the former Union of Soviet Socialist Republics (USSR). Post-1949 and the founding of the People's Republic of China, the country was very isolated internationally and not integrated in mainstream global efforts to scale up technology transfer to developing countries in the 1950s [21].

Pharmaceuticals and biotech have become an increasingly important industrial sector for China in the last two to three decades, however, and increasing investment and policy support have sought to transform an industry primarily focused on generics and 'me too' drugs into one focused on value and innovation [22–24]. China's antibiotic exports have developed rapidly, as part of an export-oriented pharmaceutical manufacturing strategy, but as with other segments of the market, antibiotic exports are primarily concentrated in APIs and generic drugs [11, 25]. There is recognition of the need for the country's antibiotic sector to transition toward innovation-driven growth, balancing the country's traditional role as a fast follower in antibiotics [22].

China has introduced a series of strategic national policies to elevate its position in global value chains. In 2017, the country set the goal of "promoting the country's manufacturing industry to move up the global value chain." This objective was reiterated in 2020 and 2022 with an emphasis on "enhancing the autonomy, security, and control of industrial and supply chains" [26]. Regarding antibiotics, China has introduced various policies to encourage and support the R&D of next-generation antibiotics, accelerate their commercialization, and

streamline the approval process for new drugs [27]. These measures have, to some extent, promoted competition between domestic and international new drugs in the local market, driving innovation among domestic pharmaceutical companies [28, 29]. The most notable example is the "National Action Plan to Contain Antimicrobial Resistance (2016-2020)" [30]. In recent years, Chinese companies have gained international certifications from agencies including Food and Drug Administration (FDA), Certificate of Suitability (COS), the Pharmaceuticals and Medical Devices Agency (PMDA), Therapeutic Goods Administration (TGA), and Therapeutic Products Directorate (TPD), enabling them to export to high-end global markets and enhancing their international competitiveness [31].

The COVID-19 pandemic has had a profound impact on global supply chains [32]. Before the pandemic, concerns had already been raised about the risks of relying on China's pharmaceutical supply chains, but these issues gained greater attention and urgency in the wake of the global health crisis. Countries, led by the US, began rethinking the global layout of their manufacturing supply chains [33, 34]. China's antibiotic industry faces multiple pressures, including the need to strengthen domestic innovation, dependency on trade in comparatively lower-value antibiotic ingredients, and pressures likely to come from the reshaping of global antibiotic ingredient supply chains. Therefore, assessing China's role in the global antibiotic supply chain, optimizing the pharmaceutical industry landscape, and enhancing international competitiveness have become critical. In this study, we aim to clarify China's role in the global antibiotic industry chain by analyzing China's evolving antibiotic trade and exploring the changing trends in the comparative advantage of Chinese-produced antibiotics.

Materials and methods

Data

Classification and definitions

When products cross borders through regular trade, they are usually recorded in trade registers using the international nomenclature referred to as the Harmonized System (HS) developed by the World Customs Organization (WCO). Products are usually identified by a six-digit code [35]. HS Chapter 29 (Section 2941) and Chapter 30 (Section 3003 and 3004) cover different antibiotic products [9].

We use 'antibiotic ingredients' in this article to refer to what is often called either Active Pharmaceutical Ingredients (APIs), raw chemicals, key starting materials or bulk drugs. When using the term 'antibiotic medicines' in this article, it refers to what is often called formulations, which are mixed medicines prepared for therapeutic or prophylactic uses that are exported either in doses or packed for retail sale, or in bulk without packaging. Antibiotic medicines are usually classified in the HS as pharmaceutical products under chapter 30, while antibiotic ingredients are classified as organic chemicals under chapter 29 and HS heading 2941. Antibiotic medicines are further divided into two main sub-categories in customs: (1) penicillins, streptomycins and their derivates, categorised under HS heading 3003.10 (not in doses/packing) and 3004.10 (in doses/packing), and (2) other types of antibiotics, categorised under HS heading 3003.20 (not in doses/packing) and 3004.20 (in doses/packing). There is no distinction between antibiotics for human and animal use in the HS, and this article therefore assumes that both are included under the mentioned headings.

Data sources, collection and analysis

The data used in this article were obtained from China Customs public database and ITC database. Data from ITC database primarily comes from UN Comtrade, the world's largest trade statistics database, which is maintained by the United Nations Statistics Division (UNSD) and is based on trade data submitted by national statistical agencies. The antibiotic products analyzed in this study are heterogenous in their physical characteristics, i.e., tablets, capsules, syrups, powders, creams, ointments or liquids, in bulk or in doses with excipients added. Working with volume or unit value was therefore not found relevant in this study [36]. Therefore, we utilize monetary value (USD) as an indicator of trade throughout, rather than quantity (volume in kilogram) or unit value (price per kilogram). We collected commodity-specific data on China's annual exports between 2002–2021 using the HS codes on antibiotics mentioned above. Data collection and analysis were conducted using Excel, while R 2.5.6 and Gephi were used for data visualization.

Methods

Descriptive analysis of trade

Analyzing China's antibiotic trade trends by the import and export value, the proportion of different products in imports and exports, and the changes in export values to major countries, focusing on the top ten countries with the highest antibiotic exports in 2021.

Global trade network

The trade network is a complex economic system composed of interconnected national or regional economies. Based on the trade data of the top ten countries with the highest antibiotic exports in 2021, trade network analysis is utilized to analyze the global antibiotic industry structure, including trade value and

partnerships. Treemaps are a popular tool for visualizing hierarchical data: items are represented by nested rectangles, with the area of each rectangle corresponding to the data for that item. Within the same hierarchy level, larger rectangles indicate a greater proportion of that data within the whole [37, 38]. The treemap is used here to illustrate China's antibiotic export markets and values, highlighting the destinations and scale of China's antibiotic exports.

Comparative advantage: definition and indicators

Comparative advantage refers to a country's ability to manufacture and export goods and products that are relatively cheaper than similar goods manufactured and exported by other countries and foreign competitors [39]. The Balassa Revealed Comparative Advantage (RCA) index measures a country's comparative advantage in exporting specific commodities relative to other countries within a free trade framework and is widely used in comparative research [40]. To quantitatively assess the comparative advantage of various antibiotic products among the leading exporting countries, this study uses the comparative advantage index to analyze the antibiotic products of the top ten countries with the highest exports of antibiotic medicines and ingredients in 2021. The formula is as follows:

$$RCA_{ij} = \left(X_{ij}/X_j\right)/(X_{iw}/X_w)$$

Where, RCA_{ij}, X_{ij}, X_j, X_{iw} and X_w are Balassa's index of revealed comparative advantage, exports of good i by country j, exports of all goods by country j, exports of good i by all countries in the world and exports of all goods by all countries in the world, respectively [41].

If the value of index is less than 1, the country has a revealed comparative disadvantage (loss) in the trade of good i and conversely, if the ratio is greater than 1, the country has a revealed comparative advantage in the trade of that good; the higher the value, the greater the comparative advantage [42]. The trend of RCA_{ij} shows the changes in export share of commodity i to country j [43]. Evaluating the incremental trend of the RCA_{ij} over time highlights the improvement in a country's competitive standing for a given commodity, reflecting the creation or utilization of new opportunities [44].

The Comparative Advantage index has limitations: 1) It is asymmetric: comparative disadvantage ranges from 0 to 1, while advantage spans from 1 to infinity. 2) There is a small-country bias: when X_j is small relative to X_w, RCA tends to be higher, often making smaller countries appear more competitive than larger ones [40, 45, 46]. In the case of China's export of antibiotics and antibiotic ingredients, the Balassa RCA index allows a robust assessment of comparative advantage.

Results

Value of China's antibiotic exports

Supplementary table.1 reveals a significant surge in China's antibiotic exports over the past two decades. In 2021, China's exports of antibiotic totaled $5.46 billion, compared to $770 million in 2002, with an average annual growth rate of 10.85%. Since 2002, China has consistently been a net exporter of antibiotic ingredients. The trade surplus has steadily risen from $0.47 billion in 2002 to $3.86 billion in 2021, reflecting an average annual growth rate of 11.70%. Notably, the COVID-19 pandemic contributed to a surge in the 2020 trade surplus, which increased by $0.31 billion compared to 2018. Figure 1 further demonstrates the yearly growth of China's total antibiotic exports since 2002. It indicates that the most significant growth periods were 2004-2011 and 2016-2021, with a noticeable spike after the onset of the COVID-19 pandemic. The trend in antibiotic ingredient exports closely aligns with this pattern. Notably, from 2002 to 2021, China's share of the global market for antibiotic exports exhibited an overall upward trend, with the most significant increase observed in the market share for antibiotic ingredients.

Overall, while the export value and global market share of both antibiotic ingredients and antibiotic medicines has been on an upward trend over the past two decades. Nevertheless, China's antibiotic exports remain focused on ingredients, though as Figure 2 shows, that the proportion of antibiotic ingredients within the total antibiotic exports has been declining. This downward trend has become more pronounced since 2008. To explore the evolution of supply structure and market demand, we also focused on imports. The import of antibiotic medicines has shown an upward trend, with import values beginning to rise rapidly in 2007 and again in 2017. As for antibiotic ingredients, imports have steadily increased since 2016, with a spike in 2019. By 2019, the import value had reached $0.69 billion (Fig. 1).

Status and position of China's global export of antibiotic medicines and ingredients from 2020 to 2021

The results show that the leading exporters of antibiotic medicines were Italy, Canada, India, and Germany, while China, Italy, India, and Switzerland were the key exporters of antibiotic ingredients (in appendix). According to statistics, in 2021, China's antibiotic exports accounted for 18.9% of global antibiotic exports, with antibiotic ingredients making up 44.5% of global antibiotic

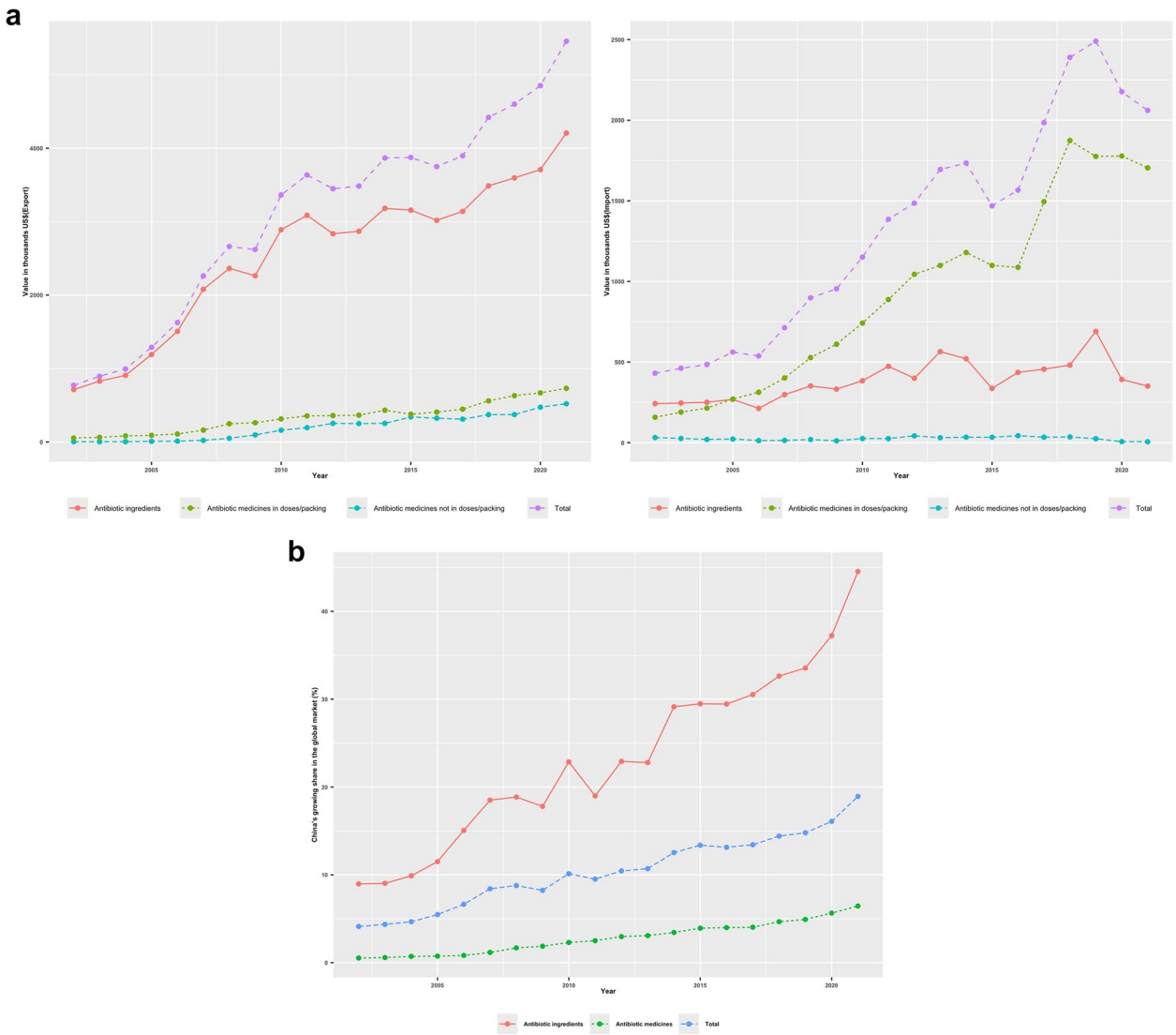


Fig. 1 **a** China's export and import trends for antibiotic medicines and ingredients (2002-2021). **b** China's growing share in the global market for Antibiotic Medicines and Ingredients (2002-2021)

ingredients exports, making China the largest exporter of antibiotic ingredients worldwide. Notably, China accounts for nearly half of the global export of antibiotic ingredients, but the number of trading partners it has is not significantly different from that of India and other countries, with considerable overlap among them. This indicates that China's export market for antibiotic ingredients is highly concentrated and faces competition from India. Interestingly, a significant portion of China's antibiotic ingredient exports goes to India (about 1/3), accounting for 82.7% of India's import share, though India is seeking to reshore API production in the wake of COVID-19 and linked to concerns over excessive reliance on overseas suppliers for critical health commodities [47]. Moreover, among the top ten exporters of antibiotic ingredients (excluding Spain and Singapore), China is also one of the main export destinations. We discuss this in more detail below.

The analysis of the antibiotic medicines trade network reveals that, aside from the relatively lower export values of the UK, the US and France, the differences in export values among other countries are not significant. The market concentration of countries' exports of antibiotic medicines differs: exports from China, the UK, France, and Belgium are relatively diversified, indicating a lower market concentration (Fig. 3a), while exports from the remaining countries are mainly directed toward one

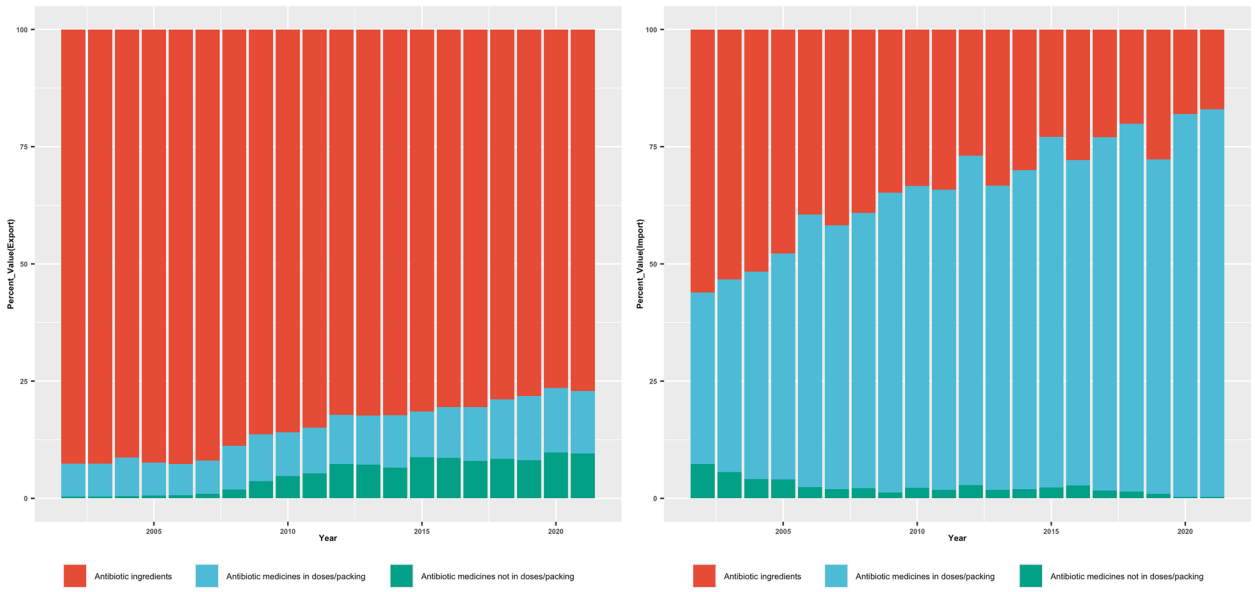


Fig. 2 Proportions of antibiotic ingredients and medicines exported and imported by China (2002–2021)

or a few key destinations, suggesting a higher market concentration.

Destinations of antibiotic ingredients and medicines exported from China

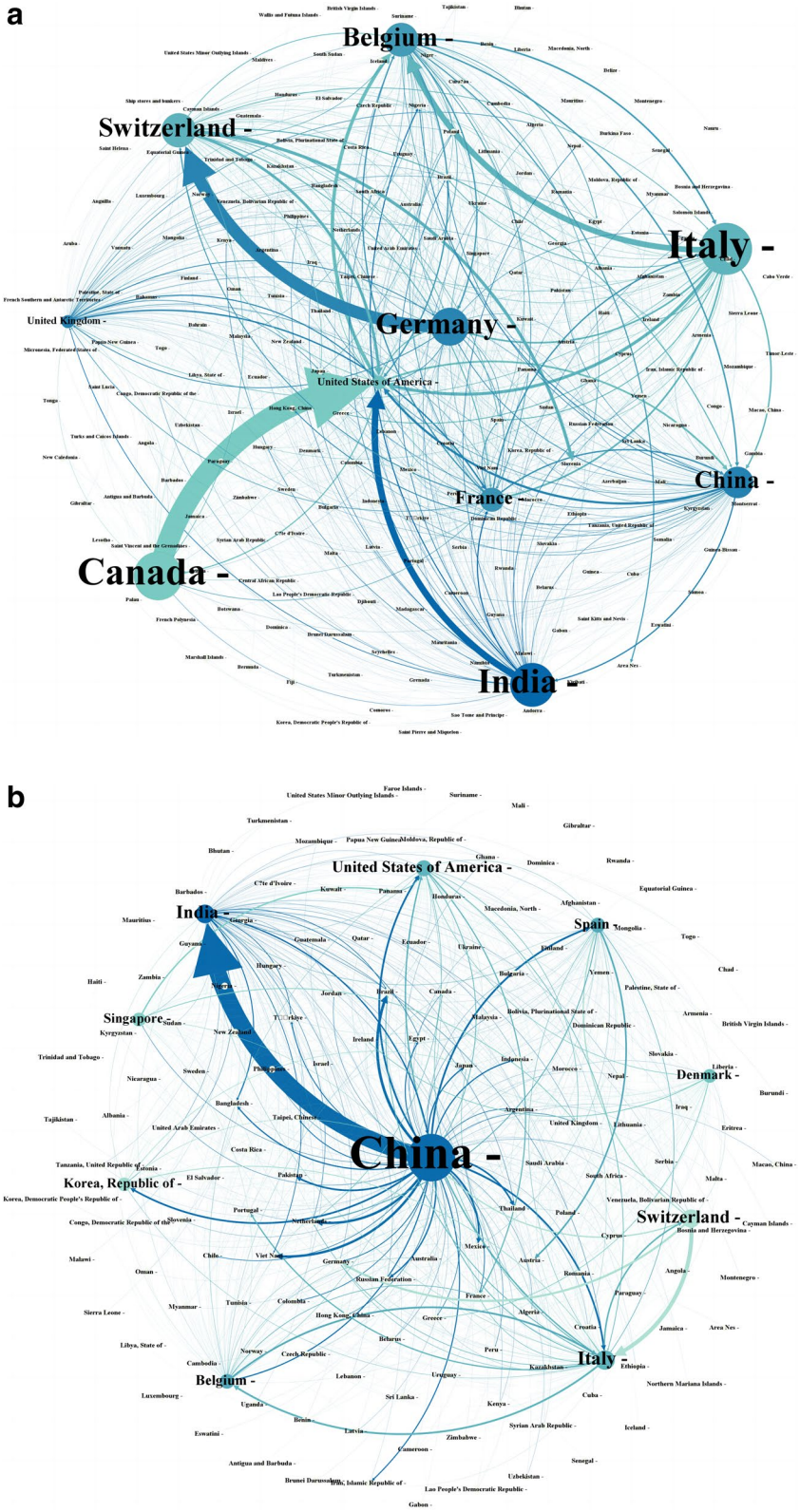
Figure 4 shows the geographical distribution of destinations for China's antibiotic exports. Taking a regional perspective, China's antibiotic medicine (penicillins, streptomycins and their derivates) export trade is predominantly directed towards West Africa, South America, Southeast Asia, and Eastern Africa. Specifically, West Africa alone accounts for over $45.36 million in exports, representing 17.09% of the total. If the focus is on countries, however, the US is the second-largest single destination for China's exports of antibiotic medicines (penicillin, streptomycin, and their derivatives). Russia, India, and Germany are also key export destinations. In contrast, the export trade for antibiotic medicines (other antibiotics) is mainly focused on countries in Western Europe, North America, South Asia, Southeast Asia, and South America, with exports to Western Europe and North America exceeding $ 270.34 million. Additionally, exports of antibiotic ingredients span all continents, with the majority still concentrated in South Asia ($ 1.55 billion). Western Europe is another major export destination. The US, Italy, Germany, and France, which are leading countries in medical innovation, account for a significant portion of China's antibiotic ingredient export value. Notably, regions with limited pharmaceutical manufacturing capacity, such as Africa, also hold a share in China's export value.

China's comparative advantage vis-à-vis the world's largest exporters of antibiotic ingredients and medicines

As depicted in Fig. 5, China's apparent comparative advantage index in the field of antibiotic medicines has consistently remained below 1, an accepted benchmark for comparative advantage in this sector, whereas Italy and India, a major exporter of antibiotics, has an index exceeding 1.5. Meanwhile, Canada's index has grown rapidly since 2018, remaining consistently above 2. In terms of market share, since 2007, China's market share in antibiotic medicines has been continuously expanding, while the global market share in antibiotic medicines has remained relatively stable. These indicate that China's export of antibiotic medicines is not a

(See figure on next page.)

Fig. 3 **a** Trade network of leading global exporters of antibiotic medicines. Node size indicates the total value of a country's exports, while node color reflects the number of exporting partner countries (darker blue denotes more partners). Line color aligns with the exporting country, and line width represents the export value to a specific target country. **b** Trade Network of the World's Leading Exporters of Antibiotic Ingredients. Node size indicates a country's total export value, while node color represents the number of export partner countries (darker blue indicates more partners). Line color aligns with the exporting country, and line width represents the value of exports to a specific target country



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comparative advantage, though this has been improving somewhat since 2007, with the index rising from 0.13 in 2007 to 0.43 in 2021, though this remains substantially below the 1 that would indicate comparative advantage. In contrast, China enjoys a significant export advantage in the field of antibiotic ingredients, with a comparative advantage index which surpasses 1.5, and which continues to grow. Both China and the world have shown an expanding trend in the market share of antibiotic ingredients, but China's growth rate is faster than that of the world. Moreover, Italy, India, and Switzerland, also major exporters of antibiotic ingredients, have a comparative advantage index generally consistently above 2, reflecting strong international competitiveness. Furthermore, the gap between China's relative advantage in antibiotic ingredients and antibiotic medicines is gradually weakening, with the relative index dropping from 18.16 in 2006 to 6.90 in 2021. Overall, the data suggests that at present and in the short term, China's export advantage in antibiotic ingredients is relatively pronounced, and that the country's comparative disadvantage in export of antibiotic medicines will take some time to be overturned.

China's export of antibiotic medicines and ingredients

Figures 6 and 7 illustrate the primary export markets for China's antibiotic ingredients and medicines, as well as the annual trends in their export values. Among the top ten export destinations in 2021, the overall export value for antibiotic medicines has been rising, with a noticeable acceleration after 2017, particularly in the US. The US has now become the main market for China's export of antibiotic medicines (other antibiotics), whereas the main market for antibiotic medicines (penicillins, streptomycins and their derivates) has shifted from Nigeria and India to Nigeria, Japan, and the US (Fig. 6). Notably, exports of antibiotic medicines (penicillins, streptomycins and their derivates) to the US started to grow in 2018 and surged in 2020, while exports to Japan saw rapid growth from 2015, reaching $23.52 million in 2018. India has consistently been the primary destination for China's export of antibiotic ingredients (Fig. 7). India has always accounted for about a third of China's export share, and the increase in exports to India has outpaced other destinations. According to statistics, antibiotic ingredients imported from China make up 82.7% of India's total imports of antibiotic ingredients by value.

Discussion

This study, based on data from the ITC, examines the evolution and characteristics of Chinese antibiotic trade from 2002 to 2021. It explores the current state of global and Chinese antibiotic export trade, as well as China's role and trends in the global antibiotic supply chain. The main findings from this research are as follows.

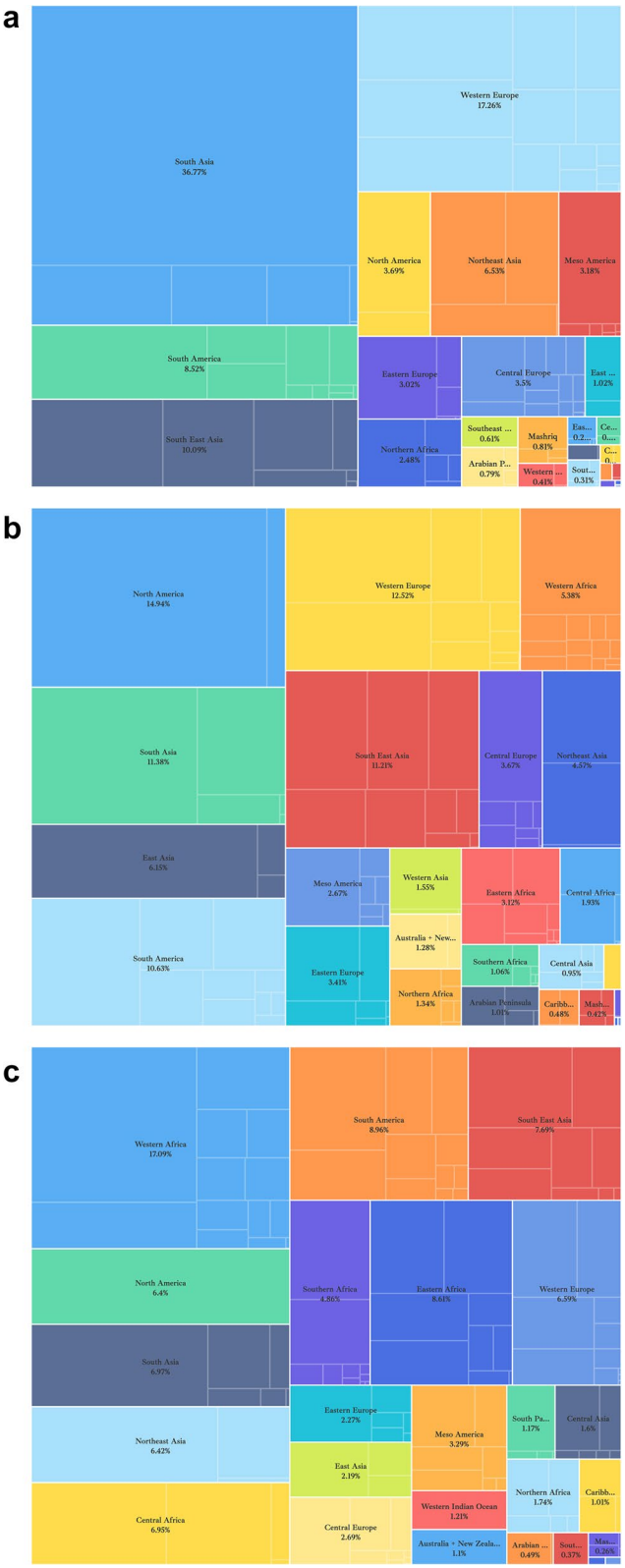
Trends in China's antibiotic export trade

China's export trade of antibiotics is influenced by macroeconomic policies. On the export side, the focus has primarily been on low - value ingredients [48], though the export of antibiotic medicines is expanding. The overall export value has shown an upward trend, driven largely by antibiotic ingredients. This can be attributed to a combination of factors, including market diversification, international environmental protection, demand patterns, and cost advantages [14, 49, 50]. The export of antibiotic ingredients surged after 2020, possibly due to the treatment of secondary infections and overuse during the COVID-19 pandemic [51–53]. The fact that, for both antibiotic medicines and antibiotic ingredients, the cumulative growth rate of the export *volume* is lower than that of the export *value* indicates a significant increase in the average unit price. This suggests ongoing industrial restructuring, with a gradual shift from lower-value to higher-value products. Additionally, the export value and proportion of antibiotic medicines vis-à-vis ingredients have been expanding since 2008. This may be linked to policies like the Medium- and Long-Term Science and Technology Development Plan (2006-2020), issued in 2006 [30], aimed at enhancing the quality of medicines. The Major Projects Plan, established in 2008, which prioritizes new drug R&D, may have also played a role [54].

On the import side, there was a significant surge in antibiotic medicines imports in 2007 and 2017, with a steady increase in antibiotic ingredient imports starting in 2016, culminating in a sharp spike in 2019. This trend can be explained by various favorable policies, including improved import regulation, reduced import barriers, initiatives to promote generic drug consistency, and supply-side structural reforms in the pharmaceutical sector [55]. Notable policy changes include the 2007 revision of the Drug Registration Regulation, the 2016 Guideline for

(See figure on next page.)

Fig. 4 Destination distribution of China's antibiotic exports in 2021. **a** Antibiotic Ingredients. **b** Other Antibiotic Medicines. **c** Penicillin, Streptomycin, and Their Derivatives. Different colors represent distinct regions. The size of the rectangles at the first level represents the proportion of the total value of China's exports to that region relative to the total value of China's exports. The size of the rectangles at the second level represents the proportion of the total value of China's exports to that country relative to the total value of exports to that region. The larger the area of the rectangle, the greater the proportion



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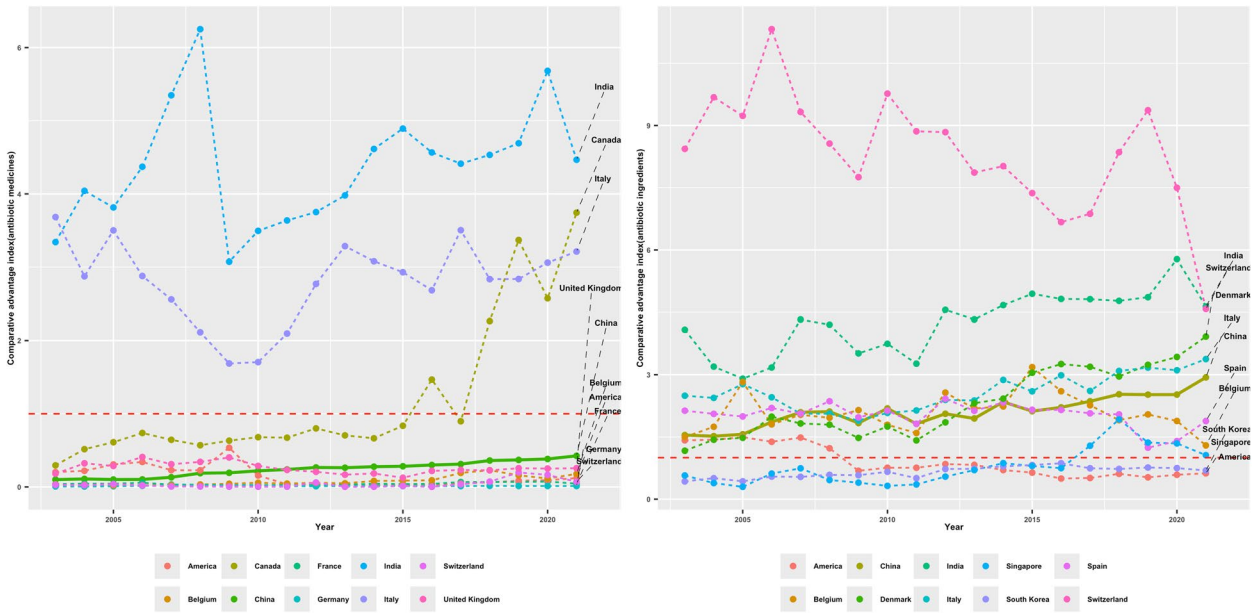

Fig. 5 Comparative advantage index of leading antibiotic exporters

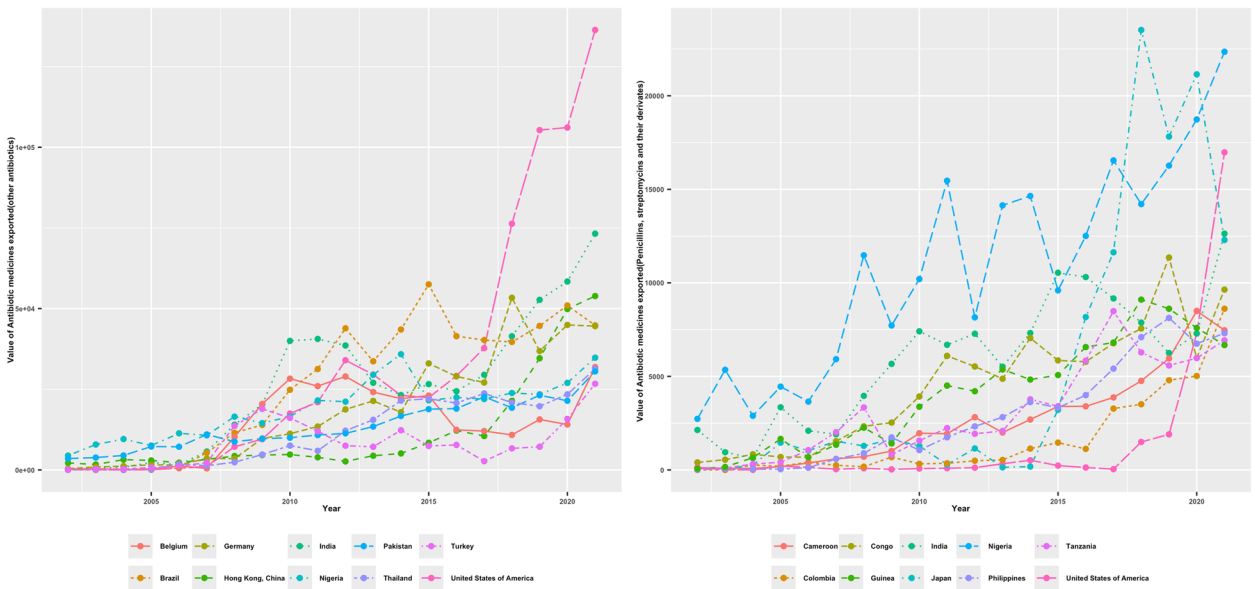

Fig. 6 Trends in export value of major Chinese antibiotic medicine exporters (2002-2021)

the Consistency Evaluation of Generic Drug Quality and Efficacy, the 2017 Classification Guidance for Generic Drug Quality and Efficacy Consistency Evaluation, and the 2018 National Drug Safety 12th Five-Year Plan [56]. The implementation of drug consistency evaluations has driven demand for high-quality imported ingredients and medicines. Environmental challenges leading to shortages or price spikes for ingredients, coupled with multinational companies' increasing procurement from overseas, have likely further spurred significant growth in imports [57]. The cumulative growth rate of imports for antibiotic ingredients and medicines is lower than that of import value, indicating an increase in average unit value. This may suggest that China's industrial structure is adjusting, with import demand remaining focused on higher-value products.

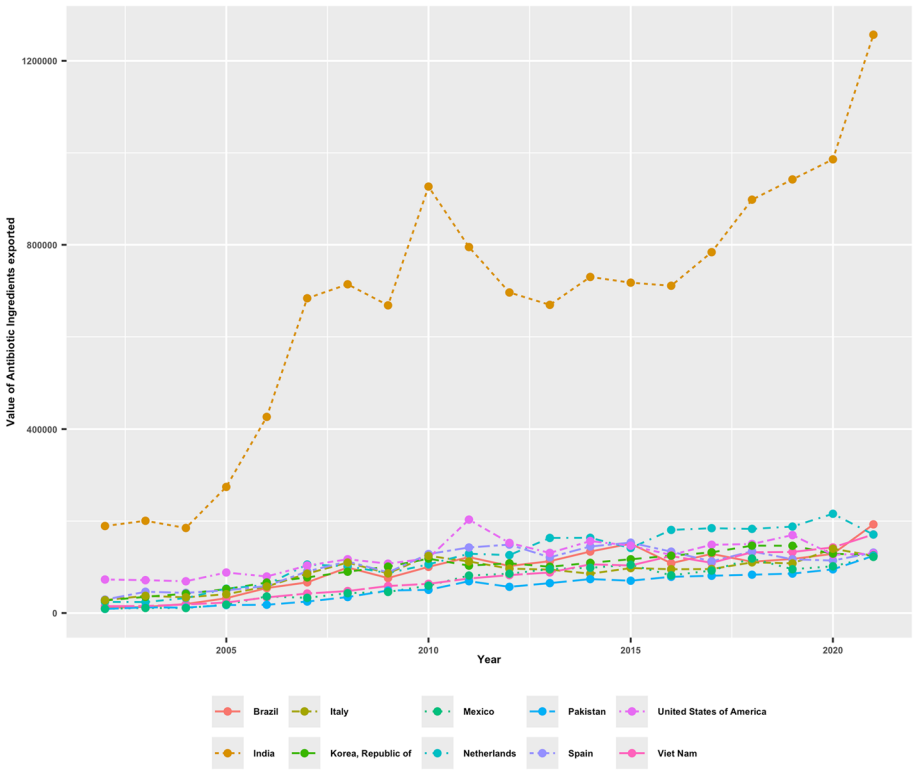

Fig. 7 Trends in export value of major Chinese antibiotic ingredient exporters (2002–2021)

Overall, China's antibiotic industry holds a position in the upstream-to-midstream segment of the global antibiotic supply chain [51–53, 58]. The worldwide supply of antibiotic ingredients is, to a substantial extent, dependent on China's exports. China is now the world's 7th largest exporter of antibiotic medicines and the largest exporter of antibiotic ingredients. Noticeably, India's antibiotic ingredients are relatively dispersed [59], whereas China's antibiotic ingredient exports are relatively concentrated in a small number of markets. About 1/3 of those exports go to India, making up 82.7% of India's total imports. As a major exporter of antibiotics, India today is highly dependent on importing antibiotic ingredients from China [9]. Consequently, the antibiotic manufacturing industry in many countries relies, either directly or indirectly, on China, positioning China as a critical player in the global antibiotic supply chain. This phenomenon was illustrated in 2017, when the shutdown of a single factory in China caused a worldwide shortage of the cornerstone antibiotic piperacillin–tazobactam [20, 60].

However, this concentration of export markets heightens the reliance of Chinese exports on specific regions. If there were issues with exports to India, for example, it would be difficult to offset them through stability or counterbalancing in other export markets [50]. Presently, countries are placing more emphasis on reshoring ingredient production, which could pose challenges for China [33, 34]. Some of the most active measures are likely to come from the United States' Biosecure Act, which will reduce US companies' ability to do business with certain Chinese companies [61, 62]. Similarly, Indian policies to reshore API production are likely to be significant for China, given the weight of India in Chinese exports [47, 63, 64]. Equally, increasing environmental regulation of antibiotic production may also affect China [65]. It is not yet clear over what timeframe this is likely to alter the global supply structure or the potential size of the impact of measures such as these [50].

Conversely, China's antibiotic medicine export market is not highly concentrated, with exports going to a large number of countries, indicating that it may be in a growth phase. This dispersion reduces economic risk but increases trade costs, suggesting China may lack competitive high-tech and high-value-added products [50]. Interestingly, China is also a primary export destination for other major antibiotic ingredient exporters, likely due to the domestic demand for high-quality, high-value ingredients. This points to the potential for China to optimize its product structure and focus on precision and specialization [48].

China's antibiotic export trade network has extended to all corners of the globe, with a growing importance

in developed markets like Europe and North America. The export markets for China's antibiotic ingredients span various continents, with a strong focus on South Asia and Western Europe. The primary markets for antibiotic medicines (penicillins, streptomycins and their derivates) are developing regions such as East and West Africa, South America, and Southeast Asia. Exports to the US started to grow in 2018 and showed a sharp increase in 2020, while exports to Japan surged in 2015. As for antibiotic medicines (other antibiotics), their primary export destinations include Western Europe, North America, and South Asia. Exports to the US began to grow in 2016, showed an accelerated increase in 2018, and reached another peak in 2021. This surge might be influenced by the overuse of antibiotics during the COVID-19 pandemic [51–53, 58]. It also reflects the impact of consistency evaluations for generic drugs [56] and other incentive policies aimed at boosting drug R&D [30, 66–68], which have improved drug quality, international recognition, and competitiveness, thereby driving exports [69]. The growing importance of the European and North American markets suggests a more rational and balanced global market distribution [23, 41].

China's competitive advantage in antibiotics

China's competitive advantage in antibiotic ingredients is likely to remain strong, whereas antibiotic medicines remain insufficiently competitive and are expected to continue to show a comparative disadvantage in the short term. The comparative advantage of antibiotic ingredients has shown a fluctuating upward trend, primarily due to costs associated with labor and the environment [70]. The comparative advantage of antibiotic medicines has been rising since around 2007, likely due to incentives for R&D and changes in drug management policies.

From the relative index of comparative advantage, around 2006, China's comparative advantage in antibiotics began shifting towards antibiotic medicines, but in the short term, the export advantage of antibiotic ingredients will continue to dominate. The factors behind this transition likely include technological advancements like increased labor productivity, and enhanced innovation capacity. Policy support, resource endowment, economies of scale, and ingredient costs have also played significant roles [71]. This evolution suggests that China's antibiotic export trade structure is being optimized, transitioning towards innovation, with industrial competitiveness strengthening and moving towards the higher end of the global industrial chain [72]. From the perspective of China's domestic industry and industrial policy, it will be important to pursue consolidation and enhanced comparative advantage, strengthen independent innovation capacity, drive technological progress, and mitigate the adverse effects of declining labor supply, rising ingredient costs, and the appreciation of the effective exchange rate [71].

A curious finding noted above is that, as well as being among the top ten exporters of antibiotic ingredients (excluding Spain and Singapore), China is also one of the main export destinations. This is a surprising finding, and possibly indicates that China is importing comparatively higher quality antibiotic ingredients from these countries, or that multinational companies in China are purchasing ingredients from outside China (Fig. 3b). More research is needed to verify this.

Global antibiotic value chains

The COVID-19 pandemic has underscored China's centrality in the supply of many health commodities [34], reviving discussions about reshaping global production networks. Overall, from a global perspective, COVID-19 has shown the importance of diversified and resilient supply and value chains in ensuring access to key medical technologies and commodities. As discussed above, countries like the US and India have implemented a series of incentives to boost domestic production of antibiotic ingredients [33, 73]. Reshaping the supply chain may not be achieved in the short term, but in the long run, it poses challenges for Chinese policymakers and industry [34, 50]. These include strengthening independent innovation and quality certification, boosting international competitiveness, and diversifying markets and export destinations [74, 75], supported by sound policies [34].

As we highlight above, access to antibiotics is a fundamental question for global health. The lack of adequate access is assessed to cause more deaths globally than antimicrobial resistance and furthers the emergence of resistance, predominantly in LMICs [76]. Faced with this, there is a need for greater support to initiatives and coordination to improve access to the right antibiotic at the right time. This is both a consideration for global health equity and for the sustainable management of antibiotics as a global good. It is also an important consideration in the negotiation of a pandemic treaty, given the importance of antibiotics in treating secondary bacterial infections in the case of a viral pandemic as well as in the management of possible bacterial threats [2]. China's significance in global antibiotic value chains, its huge manufacturing capability (and linked cost advantages in the supply of many health commodities), as well as its rapid scientific and technological progress, inevitably make the country an important part of arrangements that are needed to ensure equitable global access to antibiotics in the future [1].

This study also has limitations. Although volume or unit value is not found to be a relevant measure in this study, analyzing only trade value may overlook the pricing of more specific types of antibiotics in different markets and how prices may be affecting trade [36]. Additionally, the unit value of antibiotics exported from China is relatively low compared to other major antibiotic-exporting countries in Europe and America. Consequently, China's export share of antibiotics, calculated based on export value, may be underestimated compared to calculations based on export volume.

Conclusion

This study shows that China's antibiotic exports focus mainly on antibiotic ingredients, though the share of antibiotic medicines in exports is gradually increasing. China's comparative advantage is shifting gradually towards antibiotic medicines, though it will remain in antibiotic ingredients in the short term.

The study also shows how central China is to global antibiotic manufacturing. This is likely to make China central to future efforts to ensure global access to antibiotics, which is inequitable and a substantial cause of mortality.

This centrality also creates dilemmas as countries reshore production of pharmaceuticals and ingredients in the wake of COVID-19 to diversify their production and make their supply chains more resilient. Such dynamics will impact Chinese exporters, though they may not fundamentally alter the global supply structure in the short term.

This also has implications for Chinese policymakers and the measures they take to move Chinese pharmaceuticals up the global value chain through strengthening innovation and quality certification, boosting international competitiveness, and diversifying markets and export destinations.

China's centrality in global antibiotic value chains, its immense manufacturing capacity, and rapid scientific and technical progress pose questions about the country's evolving role in global health and desire to contribute to the provision of global public goods for health [77]. Antibiotics may be an area where the country can play a distinctive role, including through participation in negotiations over global instruments such as the pandemic treaty, or in partnering with counterparts in, for example, Sub-Saharan Africa to support technology transfer and industrial upgrading.

Abbreviations

COVID-19	Coronavirus disease 2019
AMR	Antimicrobial Resistance
LMICs	low- and middle-income countries
WHO	World Health Organization
WTO	World Trade Organization
ITC	International Trade Centre
APIs	Active Pharmaceutical Ingredients
FDA	Food and Drug Administration
COS	Certificate of Suitability
PMDA	the Pharmaceuticals and Medical Devices Agency
TGA	Therapeutic Goods Administration
TPD	Therapeutic Products Directorate
HS	the Harmonized System
WCO	the World Customs Organization
UNSD	the United Nations Statistics Division
RCA	Revealed Comparative Advantage
USSR	Union of Soviet Socialist Republics

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

Conceptualization, Y.Y, L.H and Y.H. Methodology, Y.Y and Y.H. Analysis, Y.Y, L.H, Y.H. Data collection, Y.Y. Writing–Original Draft Preparation, Y.Y, L.H, Y.H. Writing–Review & Editing, L.H, Y.Y, Y.H. Supervision, Y.H. Project Administration, Y.Y. We would like to make the following declarations: All authors of this paper have read and approved the final version submitted, and the contents of this manuscript have not been copyrighted or published previously and are not considered for publication elsewhere. The authors declare that they do not have any competing interests.

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Data availability

The datasets generated and/or analysed during the current study are available in the China Customs public database and the International Trade Centre database, [海关统计数据查询平台 (customs.gov.cn to) link to the China Customs public database; Trade statistics | ITC (intracen.org) link to the International Trade Centre database].

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Årdal C, et al. International cooperation to improve access to and sustain effectiveness of antimicrobials. Lancet. 2016;387:296–307.

2. Ren M, et al. Equitable access to antibiotics: a core element and shared global responsibility for pandemic preparedness and response. J Law Med Ethics. 2022;50:34–9.
3. Kållberg C, et al. Introduction and geographic availability of new antibiotics approved between 1999 and 2014. PLoS One. 2018;13:e0205166.
4. Outterson K, Orubu ESF, Rex J, Årdal C, Zaman MH. Patient access in 14 high-income countries to new antibacterials approved by the US food and drug administration, european medicines agency, Japanese pharmaceuticals and medical devices agency, or health Canada, 2010–2020. Clin Infect Dis. 2022;74:1183–90.
5. Francis JR. COVID-19: implications for supply chain management. Front Health Serv Manage. 2020;37:33–8.
6. Mirchandani P. Health care supply chains: COVID-19 challenges and pressing actions. Ann Intern Med. 2020;173:300–1.
7. Workman, D. Top Antibiotics Exporters by Country. World's Top Exports. 2023. https://www.worldstopexports.com/top-antibiotics-exporters-by-country/.
8. Fortunak, J. et al. Raising the Technological Level: The Scope for API, Excipients, and Biologicals Manufacture in Africa. in Making Medicines in Africa: The Political Economy of Industrializing for Local Health (eds. Mackintosh, M., Banda, G., Tibandebage, P. & Wamae, W.) 122–143 (Palgrave Macmillan UK, London, 2016). https://doi.org/10.1007/978-1-137-54647-0_8.
9. Bjerke L. Antibiotic geographies and access to medicines: Tracing the role of India's pharmaceutical industry in global trade. Soc Sci Med (1982). 2022;312:115386.
10. Chunhao, L. Can the Economic Decoupling of China by the US, Japan, India, and Australia Succeed? 2020. [美日印澳对华“经济脱钩”能成吗]. World Affairs [世界知识] 44–45.
11. Kazancoglu Y, Ekinci E, Mangla SK, Sezer MD, Ozbiltekin-Pala M. Impact of epidemic outbreaks (COVID-19) on global supply chains: a case of trade between Turkey and China. Socioecon Plann Sci. 2023;85:101494.
12. Ayittey FK, Ayittey MK, Chiwero NB, Kamasah JS, Dzuvor C. Economic impacts of Wuhan 2019-nCoV on China and the world. J Med Virol. 2020;92:473–5.
13. Zheng, Z. Research on the development and trend of China's pharmaceutical industry. [中国医药产业发展概况及其趋势研究]. Review of Economic Research [经济研究参考] 4–38.2014. https://link.cnki.net/doi/10.16110/j.cnki.issn2095-3151.2014.32.009.
14. Ministry of Commerce of the People's Republic of China. Global supply chain adjustment after the pandemic, it is difficult to knock down China's world factory. [疫后全球供应链调整 推倒中国世界工厂很难]. Ministry of Commerce of the People's Republic of China [中华人民共和国商务部]. 2020. http://www.mofcom.gov.cn/article/i/jyjl/k/202004/20200402960857.shtml.
15. Safeguarding Pharmaceutical Supply Chains in a Global Economy - 10/30/2019 | FDA. https://www.fda.gov/news-events/congressional-testimony/safeguarding-pharmaceutical-supply-chains-global-economy-10302019.
16. Chatterjee P. Indian pharma threatened by COVID-19 shutdowns in China. The Lancet. 2020;395:675.
17. Socal MP, Ahn K, Greene JA, Anderson GF. Competition and vulnerabilities in the global supply chain for US generic active pharmaceutical ingredients. Health Affairs. 2023;42:407–15.
18. Ivanov D. Predicting the impacts of epidemic outbreaks on global supply chains: a simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. Transp Res E Logist Transp Rev. 2020;136:101922.
19. Securing the supply of benzathine penicillin: a global perspective on risks and mitigation strategies to prevent future shortages | International Health | Oxford Academic. https://academic.oup.com/inthealth/article/16/3/279/7288044.
20. Tängdén T, et al. Unavailability of old antibiotics threatens effective treatment for common bacterial infections. Lancet Infect Dis. 2018;18:242–4.
21. Niansheng, C. Chronicle of antibiotic development in China. [中国抗生素发展纪事]. Chemical Industry Press [化学工业出版社]. 2021.
22. Schmid RD, Xiong X. Biotech in China 2021, at the beginning of the 14th five-year period ("145"). Appl Microbiol Biotechnol. 2021;105:3971–85.
23. China Policies to Promote Local Production of Pharmaceutical Products and Protect Public Health. 2017. https://www.who.int/publications/i/item/9789241512176.
24. Senior M. China at the threshold. Nature Biotechnology. 2021;39:789–95.
25. Mossialos, E. Pharmaceutical Policy in China: Challenges and Opportunities for Reform. 2016. https://iris.who.int/handle/10665/326313.
26. Renfa, Y. et al. Industrial agglomeration, FDI and manufacturing global value chain position. [产业集聚、FDI与制造业全球价值链地位]. Journal of International Trade [国际贸易问题] 68–81 2018. https://link.cnki.net/doi/10.13510/j.cnki.jit.2018.06.006.
27. Jiang R, et al. Research and development of mAb drugs in China: a look from policy perspectives. Human Vacc Immunother. 2019;15:2695–705.
28. National Medical Products Administration. Announcement on Adjusting the Review and Approval Procedures for Drug Clinical Trials. 2018. 网址 https://weibo.com/ttarticle/p/show?id=2309404266521269552394.
29. General Office of the Central Committee of the Communist Party of China, General Office of the State Council. Opinions on deepening the reform of the review and approval system to encourage innovation in pharmaceuticals and medical devices. 2017. https://www.sc.gov.cn/10462/13241/2017/10/9/10435279.shtml.
30. Juan, M. Outline of the National Plan for Medium - and Long-term Science and Technology Development (2006-2020). [国家中长期科学和技术发展规划纲要 (2006—2020年)]. The 9th __2006 years gazette of the State Council [国务院__2006年第9号国务院公报]. The Chinese government network [中国政府网]. https://www.gov.cn/gongbao/content/2006/content_240244.htm.
31. Jue, W. et al. SWOT analysis of the export of antibiotic preparations. [抗生素制剂出口的SWOT分析]. Enterprises in Hebei [河北企业] 19–20 2016.
32. Golan MS, Jernegan LH, Linkov I. Trends and applications of resilience analytics in supply chain modeling: systematic literature review in the context of the COVID-19 pandemic. Environ Syst Decis. 2020;40:222–43.
33. Chunhuan, M. The United States and reshape the safety of China's pharmaceutical supply chain. [美国对中国医药供应链的安全化及重塑]. Peace and Development [和平与发展] 2021;84-101+137.
34. Jia, Y. Research on enhancing competitiveness of high-tech industry in our country under the background of "de-sinicization" of supply chain. [供应链“去中国化”背景下我国高技术产业竞争力提升研究]. (Nanjing University Of Finance & Economics [南京财经大学], 2022. https://doi.org/10.27705/d.cnki.gnjcj.2021.000137.
35. Harmonized System | WCO Trade Tools. https://www.wcotradetools.org/en/harmonized-system.
36. Bjerke L. Antibiotic geographies and access to medicines: tracing the role of India's pharmaceutical industry in global trade. Soc Sc Med (1982). 2022;312:115386.
37. Sondag M, Speckmann B, Verbeek K. Stable treemaps via local moves. IEEE Transact Visual Comput Graphics. 2018;24:729–38.
38. Shneiderman B. Tree visualization with tree-maps: 2-d space-filling approach. ACM Trans Graph. 1992;11:92–9.
39. Yusefzadeh H, et al. A study of comparative advantage and intra-industry trade in the pharmaceutical industry of Iran. Glob J Health Sci. 2015;7:295–307.
40. Stellian R, Danna-Buitrago J. Revealed comparative advantages and regional specialization: evidence from Colombia in the Pacific Alliance. J Appl Econ. 2019;22:349–79.
41. Balassa B. Trade liberalisation and "revealed" comparative advantage. Manchester School. 1965;33:99–123.
42. Guo Q, You W. Assessing the competitiveness of solar photovoltaic products in comprehensive and progressive agreement for trans-pacific partnership countries. PLOS ONE. 2023;18:e0284783.
43. Balassa, B. Trade Liberalisation and "Revealed" Comparative Advantage1. in The Manchester School 99–123 (Economic and Political Studies, 1965).
44. Mansourzadeh MJ, Shahmoradi B, Dehdarirad H, Janavi E. A note on using revealed comparative advantages in scientometrics studies. Scientometrics. 2019;121:595–9.
45. Yu R, Cai J, Leung P. The normalized revealed comparative advantage index. Ann Reg Sci. 2009;43:267–82.
46. Danna-Buitrago, J. P. & Stellian, R. Which revealed comparative advantage index to choose? Theoretical and empirical considerations. 2022.
47. Ministry of Chemicals and Fertilizers. India reaches milestone with completion of 32 projects under PLI scheme. 2024.
48. Min, X. Rethinking the global positioning of China's raw material pharmaceutical industry. [中国原料药产业的全球定位再思考]. Medical Economic News [医药经济报] F02. 2021. https://doi.org/10.38275/n.cnki.nyyjj.2021.000724.
49. Feng, H. et al. Analysis of the transformation and upgrading path of late-development equipment manufacturing enterprise value chain -- Escape

from the "capture" value chain. [后发装备制造企业价值链转型升级路径分析——逃离“俘获型”价值链]. Science Research Management [科研管理] 2021;42:23–34.
50. Meiqi, S. China's export market diversification development present situation and countermeasure analysis. [中国出口市场多元化的发展现状及对策分析]. (Dalian Maritime University [大连海事大学], 2014.
51. Beović B, et al. Antibiotic use in patients with COVID-19: a 'snapshot' Infectious Diseases International Research Initiative (ID-IRI) survey. J Antimicrob Chemother. 2020;75:3386–90.
52. J. O'Neill. Tackling Drug-Resistant Infections Globally : Final Report and Recommendations. (Environmental medicine, 2016).
53. Langford BJ, So M. Antibiotic prescribing in patients with COVID-19: rapid review and meta-analysis. Clin Microbiol Infect. 2021;27:520–31.
54. National Health and Family Planning Commission. New Drugs Creation Programme of the Major Projects Programme 2015 Priority Focus Areas. 2015. http://www.nhc.gov.cn/ewebeditor/uploadfile/2014/03/20140319151530425.pdf.
55. Laijing, C. Generic drug quality and consistency curative effect evaluation analysis and countermeasure research. [仿制药质量和疗效一致性评价分析与对策研究]. (Zhengzhou University [郑州大学], 2018.
56. Feidi, Y. Study on the policy process of consistency evaluation of generic drugs in China. [我国仿制药一致性评价的政策过程研究]. (Xi'an Jiaotong University [西南交通大学], 2024.
57. Zhu, R. In 2019, China's import and export of raw material pharmaceutical products hit a new high. [2019年我国原料药产品进出口再创新高]. China Food and Drug Network [中国食品药品网] https://www.cnpharm.com/c/2020-03-15/715579.shtml.
58. Pierce J, Stevens MP. COVID-19 and antimicrobial stewardship: lessons learned, best practices, and future implications. Int J Infect Dis. 2021;113:103–8.
59. Yu Z-B, et al. Analysis of international competitiveness of the China's licorice industry from the perspective of global trade. J Ethnopharmacol. 2022;298:115613.
60. Chatterjee P. Indian pharma threatened by COVID-19 shutdowns in China. Lancet. 2020;395:675.
61. Sarah K. Rathke, Janine Little of Squire Patton Boggs (US) LLP. U.S. House Passes BIOSECURE Act to Limit Foreign Biotech Influenc. National Law Review. 2024. https://natlawreview.com/article/us-house-representatives-passes-biosecure-act-during-china-week.
62. House Passes First Tranche of China Bills, Including Biosecure Act. Inside U.S. Trade 2024.
63. Active Pharmaceutical Ingredients Business in India Gains as Pharma Firms Diversify Raw Material Sourcing from China. The Indian Wire. 2020. https://www.theindianwire.com/business/active-pharmaceutical-ingredients-business-in-india-gains-as-pharma-firms-diversify-raw-material-sourcing-from-china-279756/.
64. Manu Kaushik. US' Biosecure Act targets China, seen to double India's pharma contract manufacturing in 3 years. Financialexpress. 2024. https://www.financialexpress.com/business/healthcare-us-biosecure-act-targets-china-seen-to-double-indias-pharma-contract-manufacturing-in-3-years-3557737/.
65. WHO. Guidance on Wastewater and Solid Waste Management for Manufacturing of Antibiotics. 2024.
66. Shi Y, Rao Y. China's research culture. Science. 2010;329:1128.
67. Baolin, D. Bacterial drug resistance present situation and the research and development of resistance to antibiotic resistance. [细菌耐药的现状与抗耐药抗生素研发]. in Proceedings of the 12th National Conference on Antibiotics 9 (Antibiotics Committee of Chinese Pharmaceutical Association, China Journal of Antibiotics, China Medical Biotechnology, 2013). [第十二届全国抗生素学术会议论文集 9 (中国药学会抗生素专业委员会、《中国抗生素杂志》杂志社、《中国医药生物技术》杂志社，2013.
68. Daijie, C. Global research and development of antibacterial background situation and an antibacterial drug research and development of thinking in China. [全球抗菌药研发背景概况及对加快我国抗菌药研发的思考]. Shanghai Med J [上海医药] 2012;33:7–9.
69. Linfeng, H. et al. Industry impact of generic drug consistency evaluation. [仿制药一致性评价的产业影响研究]. Chinese Journal of Pharmaceuticals [中国医药工业杂志] 2016;47:1097–1101.
70. Yongshan, Z. et al. Current situation and innovation of science and technology system of antibiotic industry in China. [中国抗生素产业的现状与科技体系创新]. Science & Technology Information [科技资讯] 2013 233. https://doi.org/10.16661/j.cnki.1672-3791.2013.01.174.
71. Jiaqi, L. The evolution characteristic, influence factor and development tendency of our country comparative advantage. [我国比较优势的演变特点、影响因素与发展趋势]. Globalization [全球化] 112-124+135 2022 https://doi.org/10.16845/j.cnki.ccieeqqh.2022.02.012.
72. Lin, Z. Can China's antibiotic trade policy intervention enhance its comparative advantage? [中国抗生素产品贸易政策干预能提升其比较优势吗]?. (JiLin University of Finance and Economics [吉林财经大学], 2022. https://doi.org/10.26979/d.cnki.gccsc.2022.000739.
73. PIB Delhi. Approval Accorded under Production Linked Incentive (PLI) Scheme for Promotion of Domestic Manufacturing of Critical Key Starting Materials (KSMs)/ Drug Intermediates and Active Pharmaceutical Ingredients (APIs). 2021. https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?骄傲=1704143.
74. Lili, J. Research on international competitiveness of Chinese industry under global value chain division of labor. [全球价值链分工下中国产业国际竞争力研究]. (Party School of the CPC Central Committee [中共中央党校], 2008.
75. Feng, J. International competitiveness of Chinese pharmaceutical industry from the perspective of global value chain. [全球价值链视角下中国医药产业国际竞争力研究]. (Kunming University of Science and Technology [昆明理工大学], 2023. https://doi.org/10.27200/d.cnki.gkmlu.2022.001392.
76. Laxminarayan R, et al. Access to effective antimicrobials: a worldwide challenge. Lancet. 2016;387:168–75.
77. Haoran, L. Xi: China to share vaccine with world. China Daily https://govt.chinadaily.com.cn/s/202005/19/WS5ec3c3da498ede88abf83c77/xi-china-to-share-vaccine-with-world.html.

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